Telemetry and Command system design for ST5: Approach, Lessons Learned thus Far

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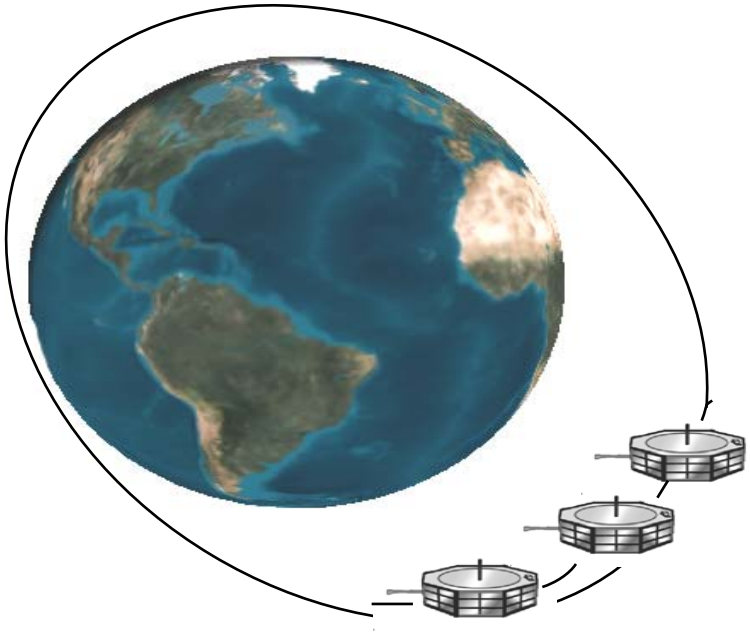
Agenda

- The problem
  - Requirements
  - Technical challenges
- Our solution
  - Design approach
  - Telemetry design
  - Command design
- Lessons learned
- My role
- Summary



ST5 New Baseline Orbit

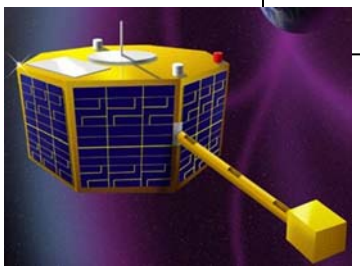
- **Launch Timeframe:** February 28 - March 31, 2006
- **Launch Site:** Vandenberg AFB, Lompoc, CA
- **Mission Duration:** 90 days
- **Eclipses:** None due to earth shadow, March 29 eclipses on 2 - 3 orbits due to moon shadow
- **Perigee:** 300 km
- **Apogee:** 4500 km
- **Inclination:** 105.6 deg (sun synchronous)
- **Period:** 136 min
- **Number of orbits/day:** about 10.5
- **RAAN:** 68 for Mar 1 launch, increasing 1 deg/day for launch later in launch window (full sun 6 AM - 6 PM)
- **Argument of Perigee at Launch:** 160 deg
- **Rotation of Apsides:** -1.2 deg/day (into the southern hemisphere)
- **Constellation Configuration:** "String of Pearls"

Requirements – ST5 Overview

- 3 identical spacecraft
- Formation fliers
  - Only one pass at a time
  - Uplink/downlink with one spacecraft at a time
- CCSDS protocols
  - Unique Spacecraft-ID for each spacecraft
  - Spacecraft-ID is present in all frames (telemetry and command)
  - One telemetry bitstream per spacecraft (due to modulation scheme)

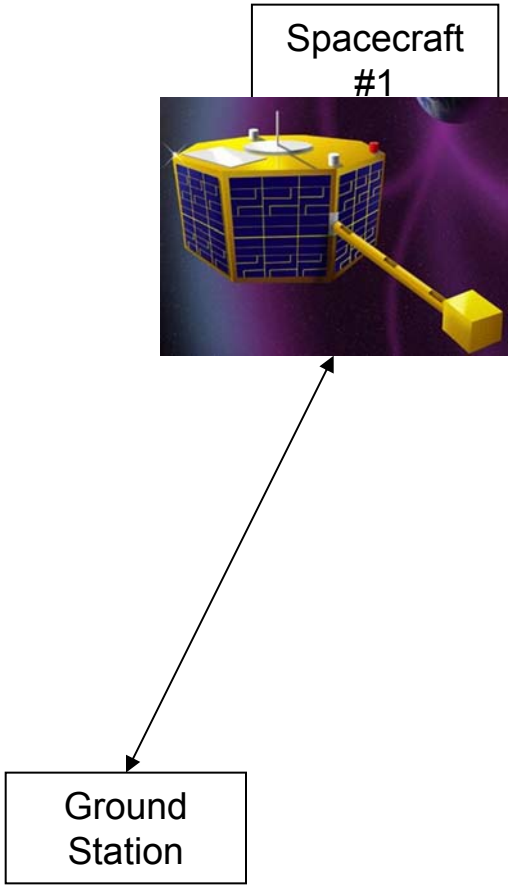
ST5 Pass (multi-slide animation)

Spacecraft #1



Ground Station

ST5 Pass (multi-slide animation)



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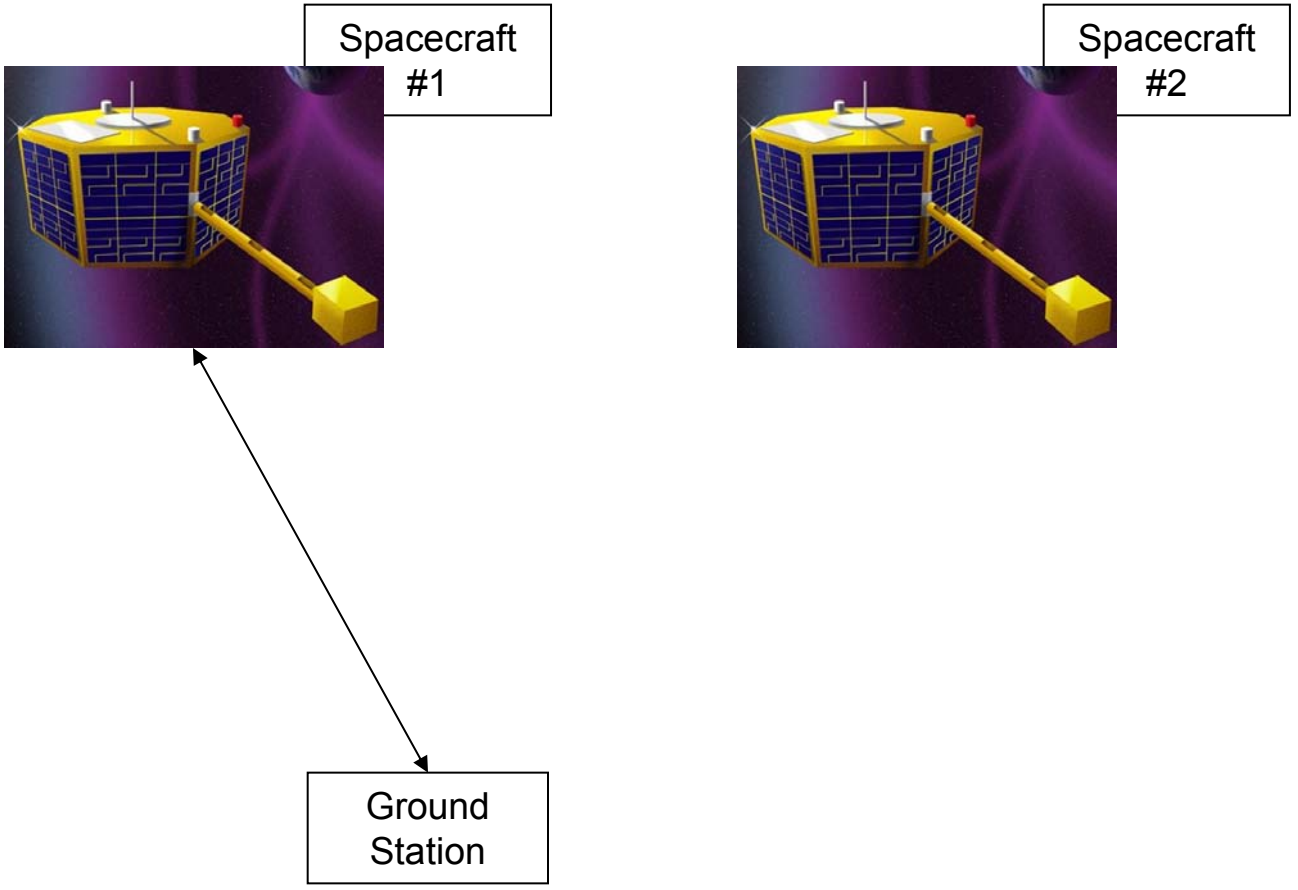

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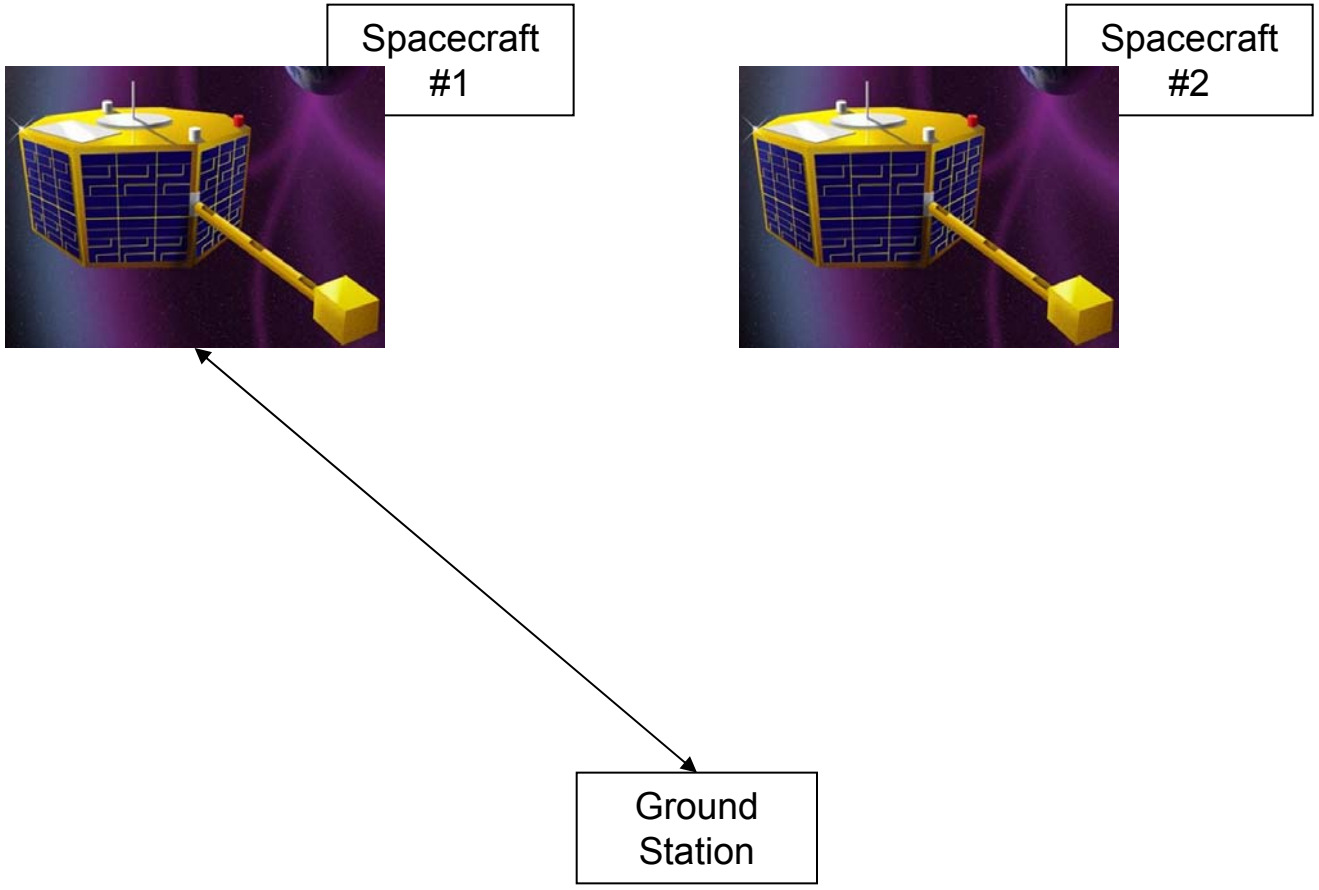

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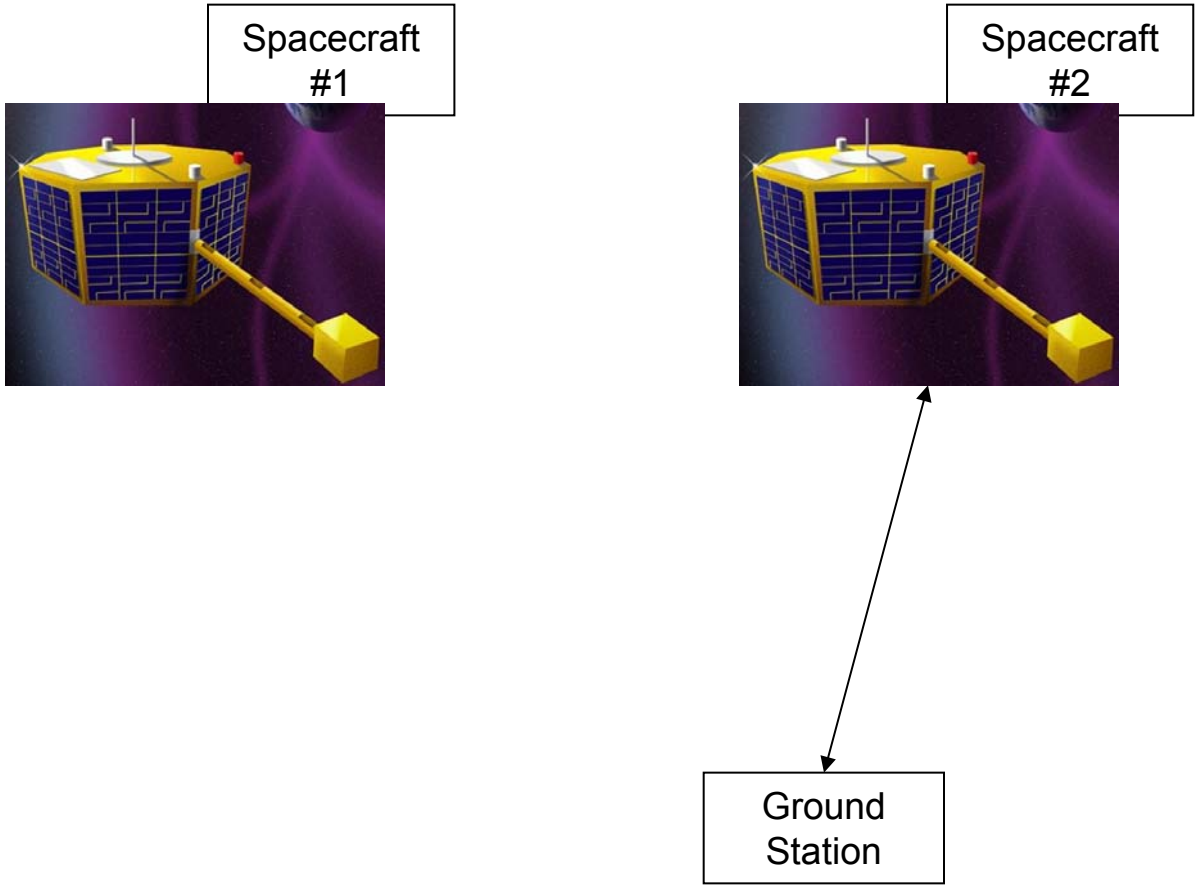

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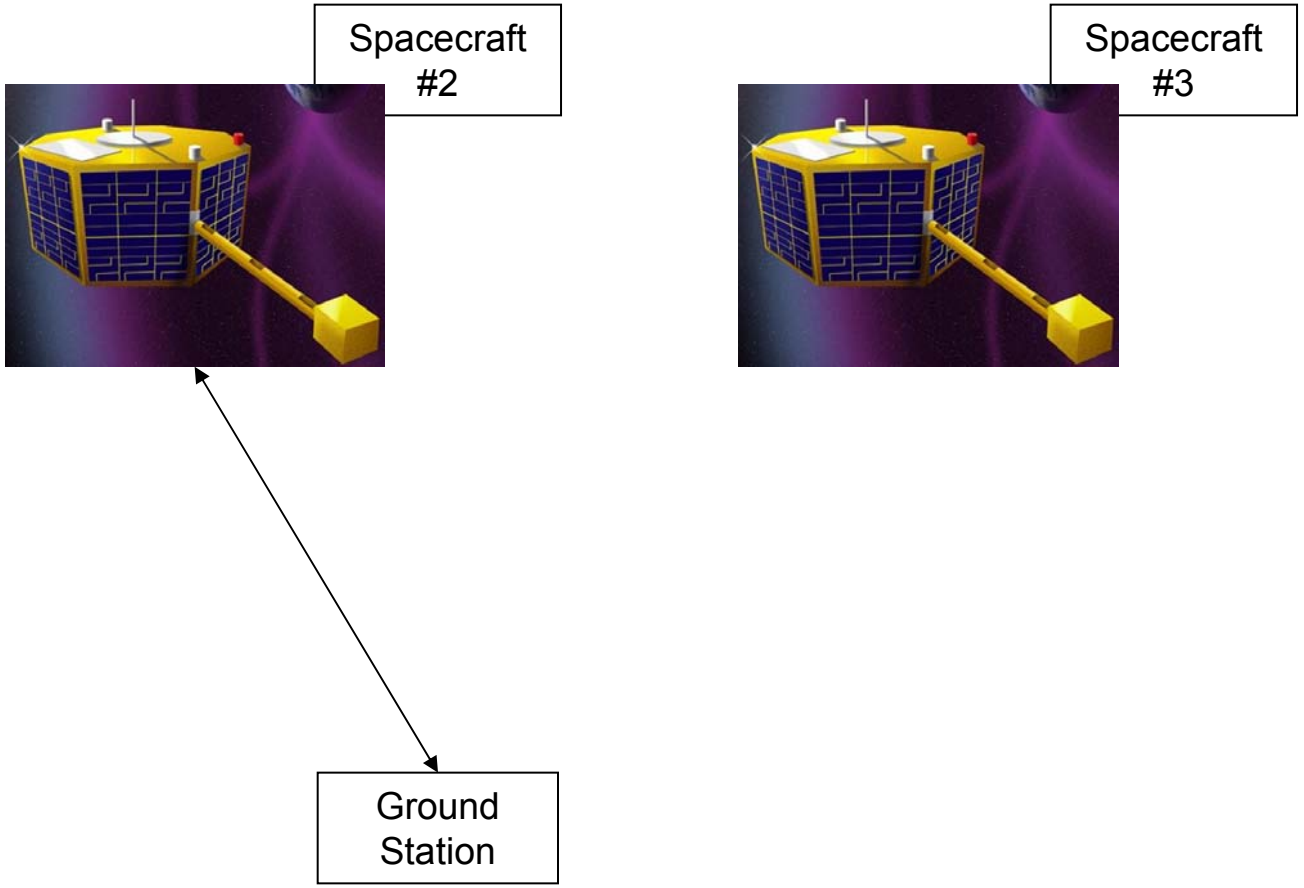

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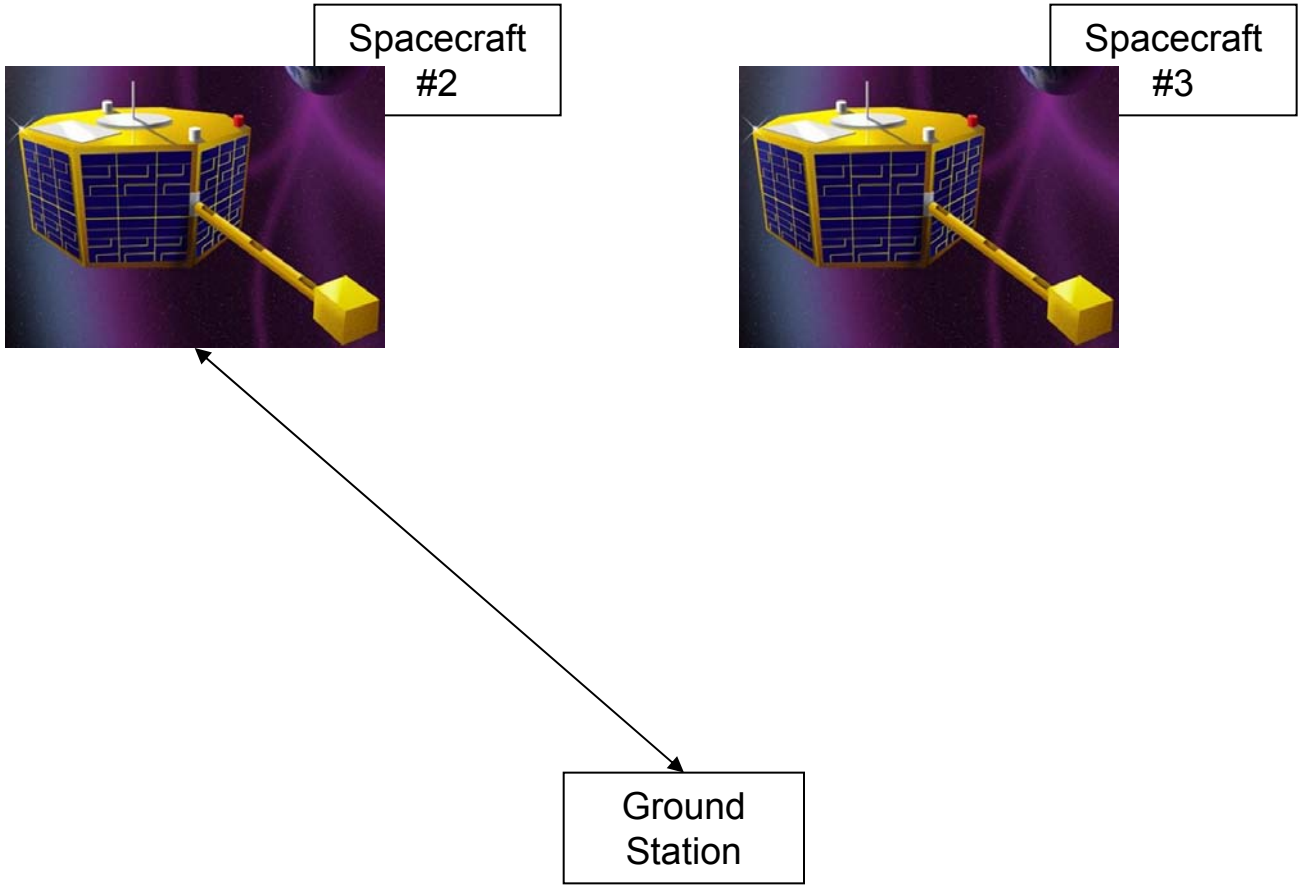

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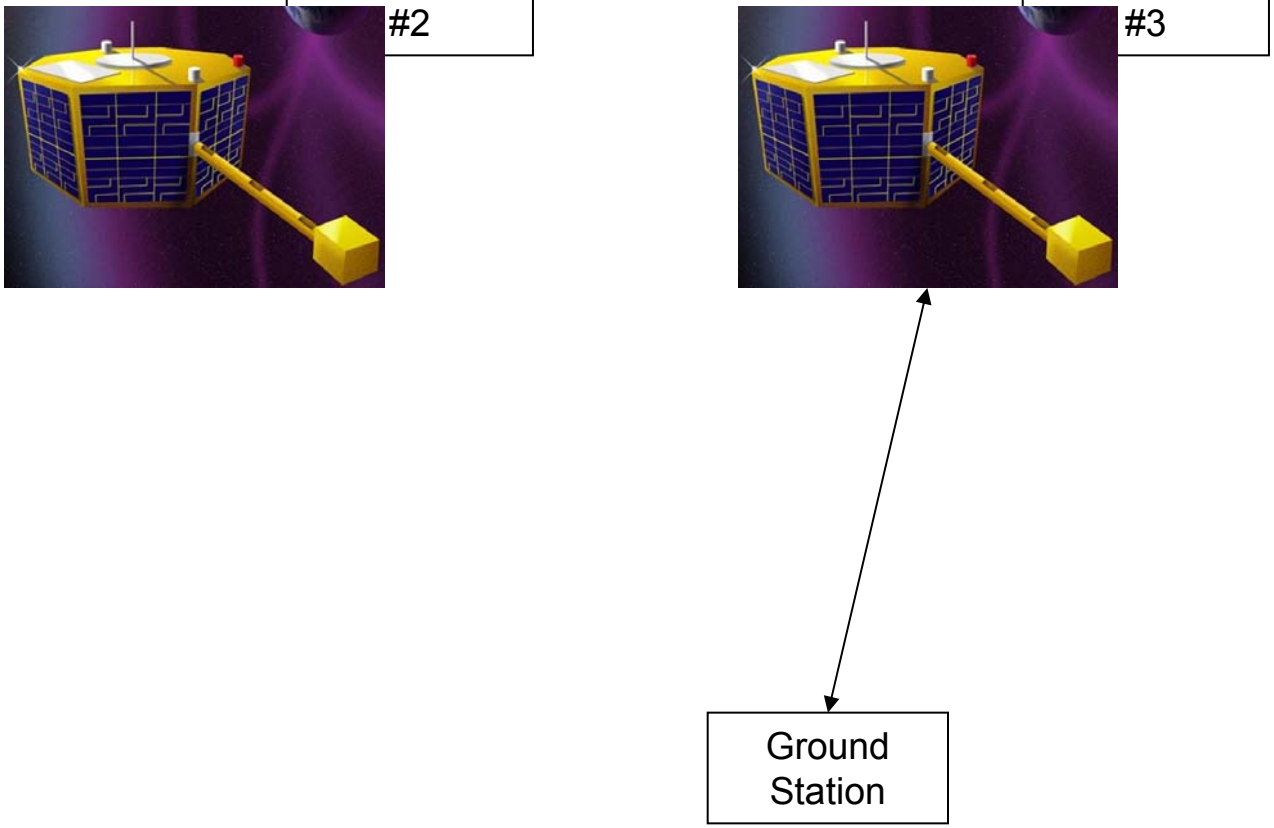

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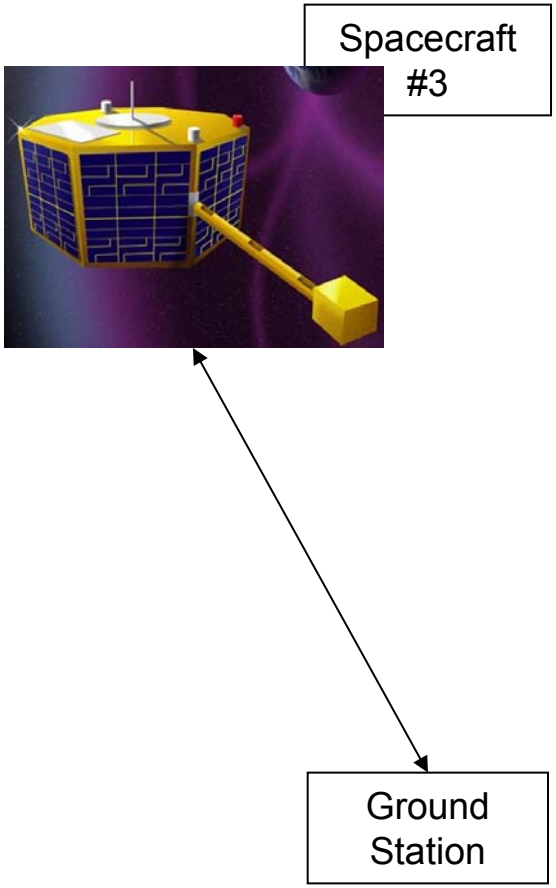

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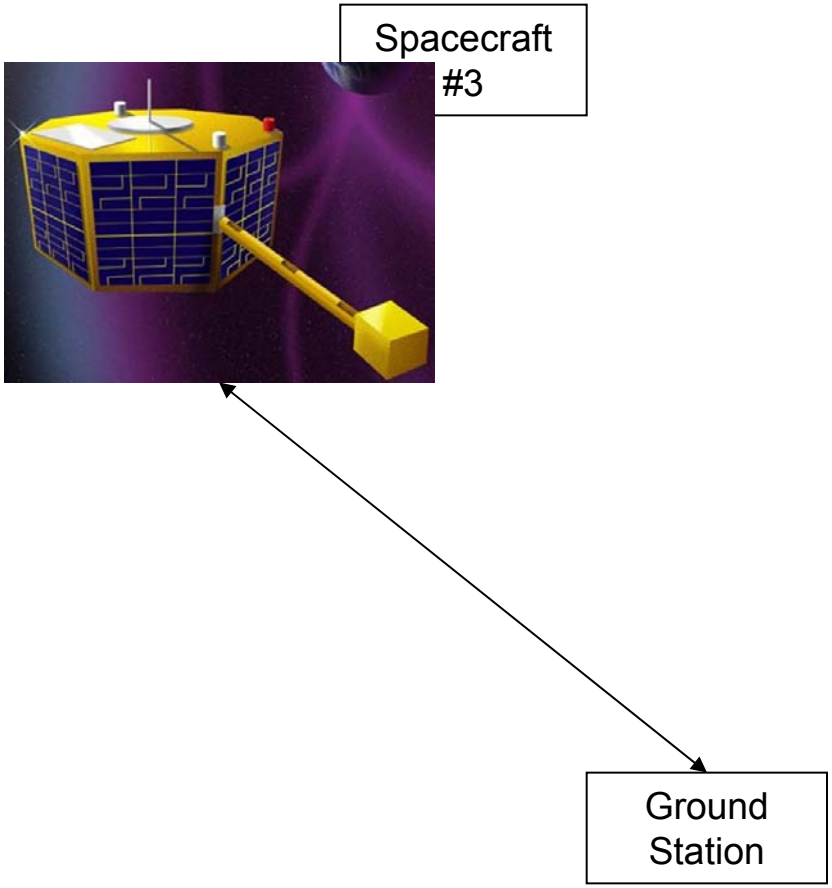
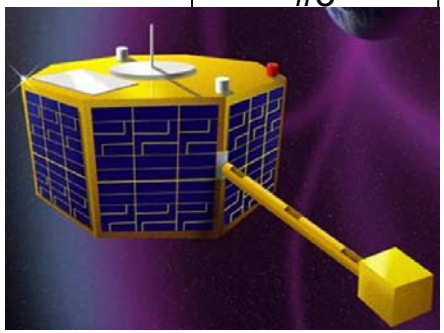


ST5 Pass (multi-slide animation)

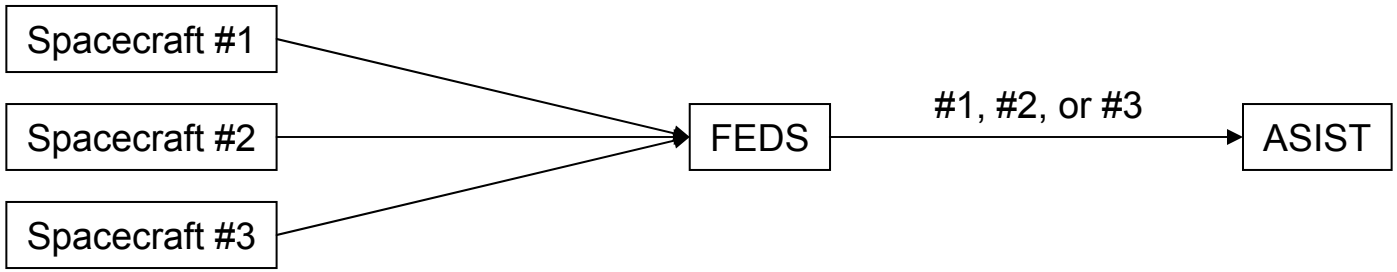
Spacecraft #3



Ground Station

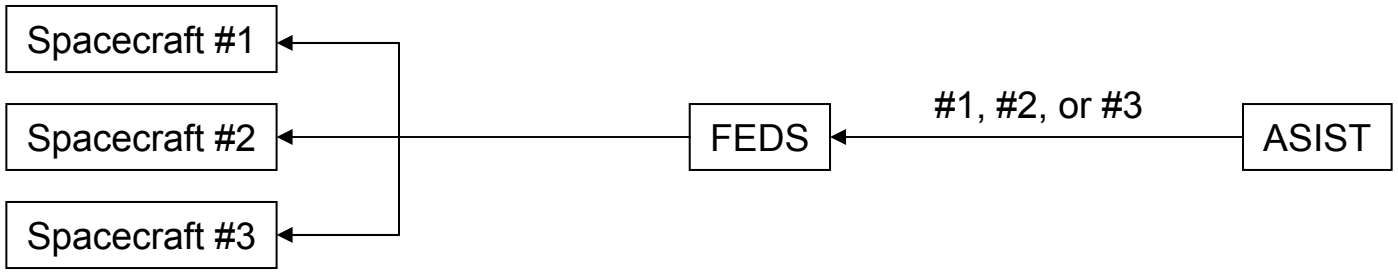
Requirements – ST5 telemetry

- I&T drives the requirements (parallel testing)
- Parallel ingest and processing (FEDS)
- Monitoring of telemetry values (ASIST)
  - Each ASIST workstation need only monitor one spacecraft at a time
  - User must be able to easily switch between spacecraft on-the-fly.
  - Parallel monitoring via multiple ASIST workstations



Requirements – ST5 commanding

- Generate commands (ASIST)
  - Each ASIST workstation need only command one spacecraft at a time
  - User must be able to easily switch between spacecraft on-the-fly
  - Parallel commanding via multiple ASIST workstations
- Three concurrent COP-1 command feedback loops (FEDS)
- Single uplink (shared by all 3 spacecraft)



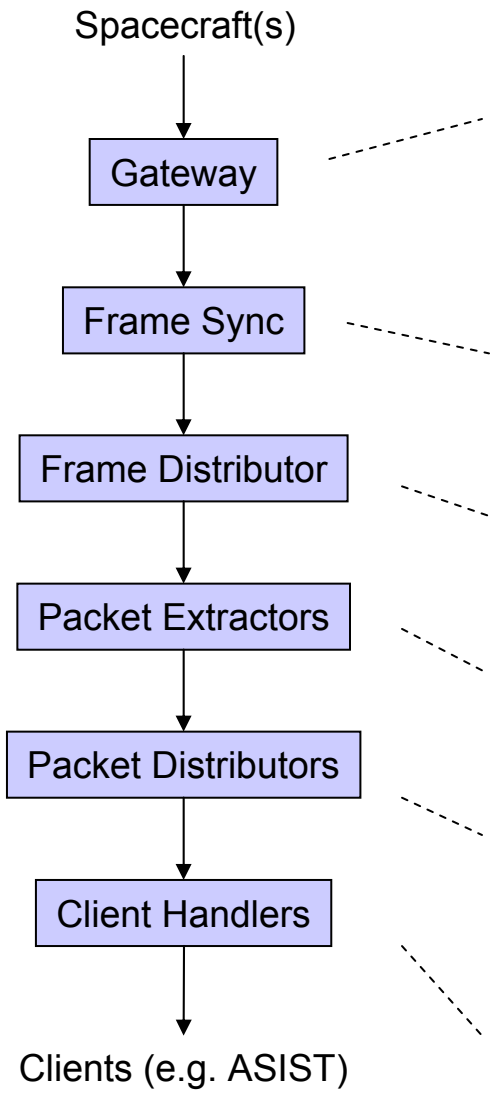
Technical challenges

- I&T is more challenging than operations
  - Parallel versus serial “passes”
- Vast amount of existing capability; don’t break anything
  - Any change to existing source code may break existing capabilities.
- Maintaining backward compatibility (self-imposed requirements)
  - Product must handle both single-spacecraft and constellation missions **…**
  - **…** with identical source code.
  - New ASIST must work with old FEDS

Design approach

- Generic solution
  - Handle a class of constellation missions (CCSDS spacecraft)
- Minimize changes to existing source code (rule of thumb)

Telemetry design (FEDS tasks)



Separate program for each interface (e.g. RS422, DSN)

ST5: Three copies of RS422-gateway task (for I&T)

Extracts frames (one task per spacecraft + Physical Channel combination)

ST5: Three copies of Frame Sync task (for I&T)

Buffers frames (one task per Physical Channel)

Removes packets from frames (one task per Physical Channel + Virtual Channel combination)

Buffers packets (one task per Physical Channel + Virtual Channel combination)

Provides packets to client as per client's subscription (one task per client)

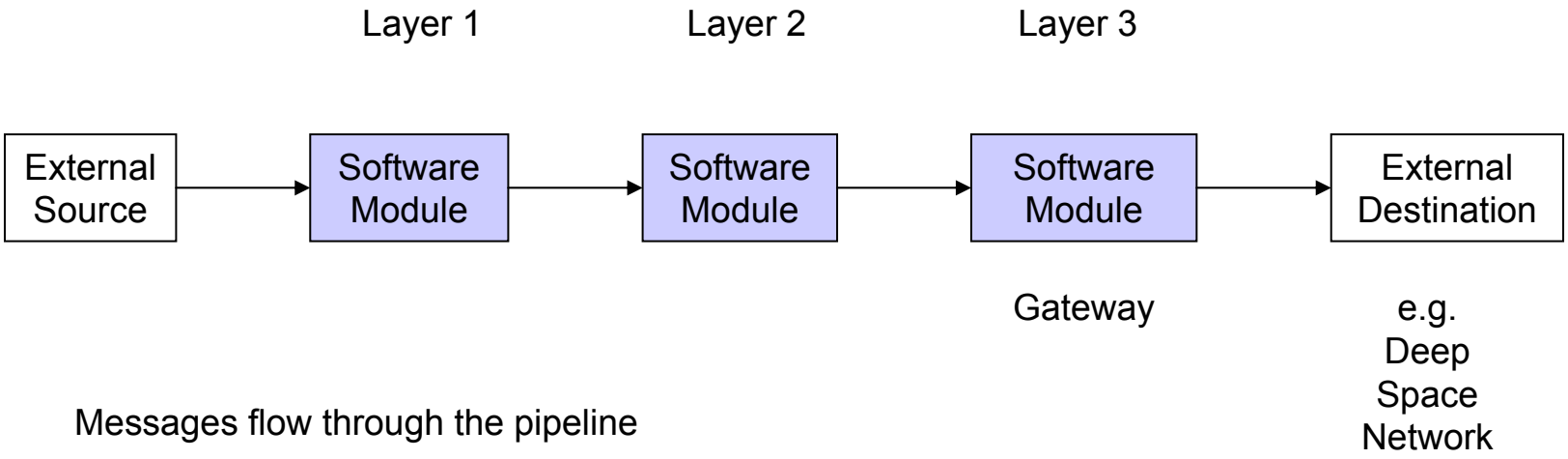
ST5: Spacecraft-ID added to the subscription parameters

Telemetry design - Implementation

- Enhanced configuration capability
  - From hard-coded scripts to an XML-based utility
- Enhanced RS422 driver
  - From one input to multiple concurrent inputs

- Added Spacecraft-ID to various algorithms/interfaces
- Enhanced command feedback
  - From one path to multiple paths

Commanding – Pipeline Architecture concept



Messages flow through the pipeline

Each module performs work (may include message conversion)

Message format is always the same…

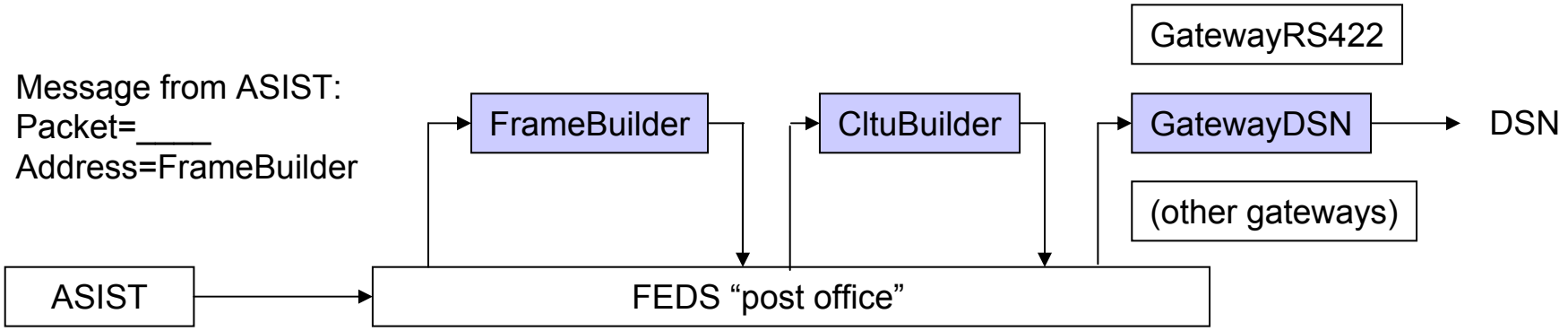
… except for Gateway module (e.g. match Deep Space Network interface)

There can be multiple modules per layer…

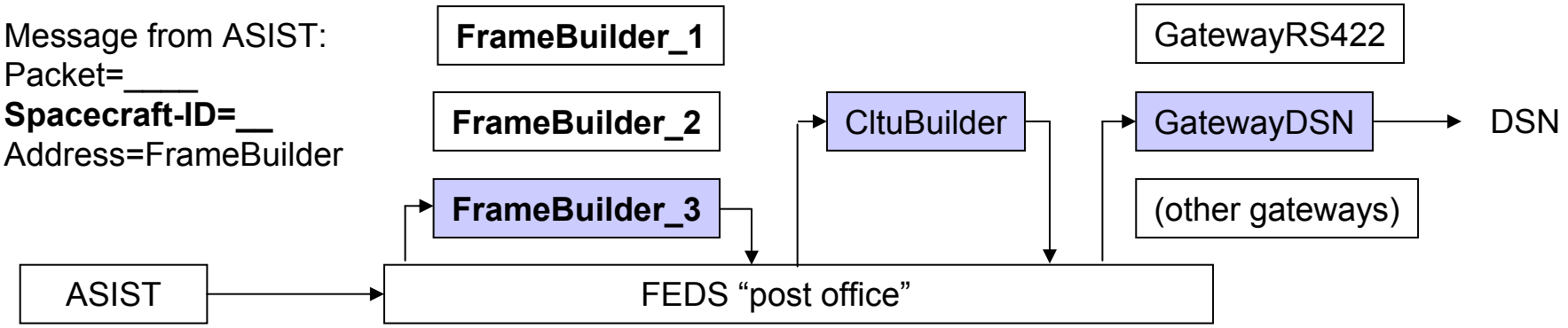
… but each message goes through one module per layer.

Command design – Pipeline Architecture

Single-spacecraft pipeline



Constellation (ST5) pipeline



CLTU = Command Link Transmission Unit (bitstream)

Command design - Implementation

- Added Spacecraft-ID field to ASIST command message format
- Added address-translation (routing) capability to FEDS “post office”
  - Generic capability; specifics via configuration files
  - Can support routing to one of n concurrent Ground Station passes
- Enhanced command feedback
  - From one path to multiple concurrent paths
- Very few source code changes
  - Less than one person-month each for ASIST and FEDS

Lessons Learned

- Design with an eye towards possible future enhancements
- Provide generic capabilities
  - Our Pipeline Architecture enabled an easy transition from commanding single-spacecraft to commanding a constellation

My role

- Co-designer of the Pipeline Architecture (with Jeff Condron)
- Implementer of all the FEDS command software

Summary -- Success

- New ASIST/FEDS delivered on-schedule to ST5 I&T
  - I&T: June 2004 – January 2006
  - Launch: Spring 2006
- Backward-compatible to single-spacecraft missions
  - Delivered to SDO labs (using identical source code)
- Supports an entire class of constellations (of CCSDS spacecraft)
  - With identical source code
  - Mission-specifics via configuration files